IMAGE ANALYSIS OF NON AQUEOUS PHASE LIQUID MIGRATION IN AGGREGATED KAOLIN

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ABSTRACT

Laboratory experiments have been conducted using NAPL in a three-dimensional rectangular acrylic model to study the migration of NAPL in double porosity soil. Double porosity is an important feature in soil due to its influence on the migration of liquids within the soil. NAPL is used as there is less research carried out to investigate the flow of immiscible liquid in double porosity soil. Toluene has been used as NAPL and aggregated kaolin have been utilized as double porosity soil. Experiments were carried out to observe the migration of NAPL by obtaining the area of migration liquid, the saturation of NAPL as well as the intensity of NAPL during migration. The experiments were conducted using kaolin aggregates with three different moisture contents which were 28%, 30% and 32% respectively. An image analysis procedure is used to analyze the migration of NAPL in aggregated kaolin as well as determining the effect of different moisture contents of aggregated kaolin in migration of NAPL. The experimental results from image analysis have shown that the migration of NAPL will increase as the moisture content increases. In conclusion, image analysis is capable of observing and visualizing the migration of NAPL based on saturation, intensity and area invaded by the NAPL in double porosity soil.

ABSTRAK

Ujikaji makmal telah dijalankan menggunakan cecair bukan fasa akues (NAPL) dalam sebuah model akrilik tiga dimensi berbentuk segi empat tepat untuk mengkaji migrasi NAPL dalam tanah keliangan dua. Keliangan dua merupakan ciri yang penting dalam tanah kerana ia akan mempengaruhi migrasi cecair dalam tanah. NAPL digunakan dalam kajian ini kerana tidak banyak kajian telah dijalankan oleh para pengkaji untuk menyiasat aliran cecair tidak larut dalam tanah keliangan dua. Toluena digunakan sebagai NAPL dan agregat kaolin digunakan sebagai tanah keliangan dua. Ujikaji telah dijalankan untuk memerhati migrasi NAPL dengan mendapatkan kawasan migrasi cecair, ketepuan NAPL dan juga keamatan NAPL semasa migrasi. Eksperimen dijalankan menggunakan tiga kandungan kelembapan yang berbeza dalam agregat kaolin iaitu 28%, 30% dan 32%. Prosedur analisis telah digunakan sebagai alat untuk menganalisis migrasi NAPL dalam agregat kaolin di samping juga mengenalpasti kesan daripada kandungan kelembapan yang berbeza dalam agregat kaolin terhadap migrasi NAPL. Hasil daripada ujikaji telah membuktikan bahawa migrasi NAPL akan meningkat apabila kandungan kelembapan meningkat. Sebagai kesimpulan, analisis imej berupaya dalam memerhati dan menggambarkan migrasi NAPL berdasarkan ketepuan, keamatan dan kawasan yang disebarkan oleh NAPL dalam tanah keliangan dua.

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LIST OF SYMBOLS

%	Percentage
cm	Centimeter
ppm	Parts per million
g	Gram
Kg/m^3	Kilogram per metre cube
min	Minute
s	Second
bpp	Bits per pixel
Cm^2	Centimeter square
Lum	Luminosity
cm^2/s	Centimeter square per second

LIST OF ABBREVIATIONS

NAPL	Non Aqueous Phase Liquid
DNAPL	Dense Non Aqueous Phase Liquid
LNAPL	Light Non Aqueous Phase Liquid
VOC	Volatile Organic Compound
HDR	High Dynamic Range
RGB	Red-Green-Blue
HSL	Hue-Saturation-Lightness
HSI	Hue-Saturation-Intensity
IAT	Image Analysis Techniques
DSLR	Digital Single-Lens Reflex

CHAPTER 1

INTRODUCTION

1.1 Background

In this modern and fast developing era, computer analysis is commonly used and widely applied in various fields including civil engineering because it enables us to see how the system in the model responds and provides an accurate database for us before the real product is produced. Besides, it also saves time and cost as we don’t need to build the prototype which is time consuming and expensive in order to obtain the result.

Image analysis is a type of computer analysis that is used to extract meaningful information from images. This includes identifying shapes, counting objects, determining colors and also measuring object properties. Edge detection, shape detectors, color-based segmentation, and image thresholding are common image analysis algorithms. A detailed statistics can be obtained from images to provide human analysts with additional quantitative and qualitative data through the combinations of these common image processing techniques with region analysis functions. Figure 1.1 shows an example of result obtained from an experiment using image analysis. From the figure, the flow of liquid with time in each stage and the saturation profile are clearly observed.

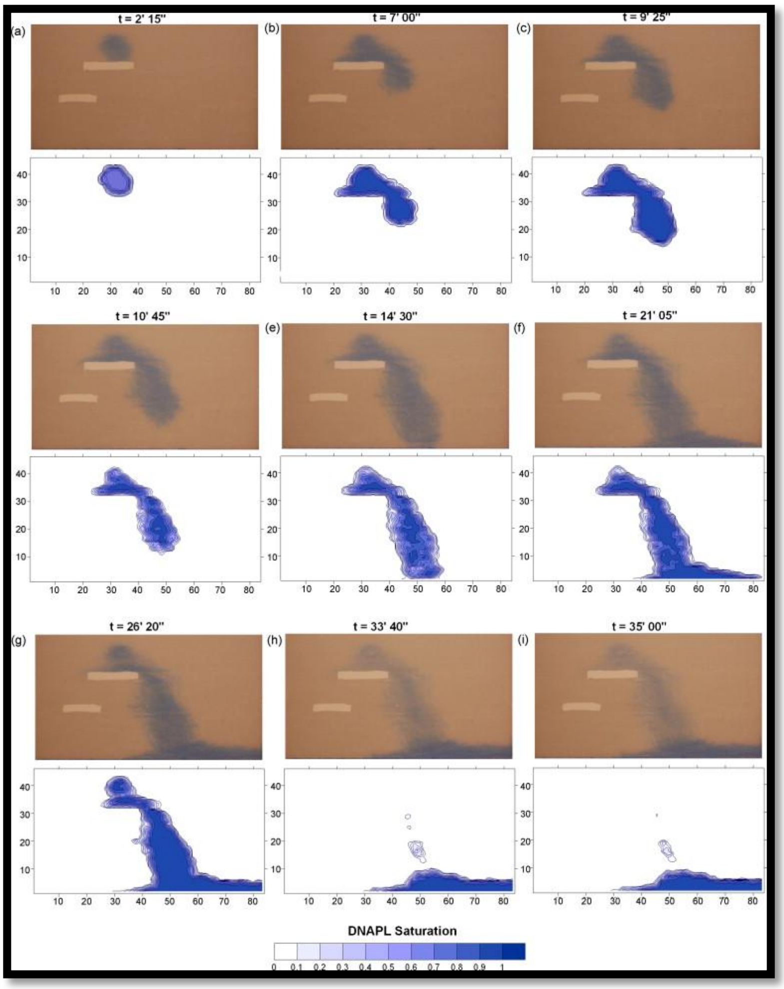


Figure 1.1: Example of result obtained from image analysis

In civil engineering, image analysis is often used to study the movement and behaviour of very small and tiny properties in a structure. For instance, void and porositiness in soils is hard to be seen with naked eyes. According to Burger and Shackelford (2001) and Mandique (2007), there were two scales of porosity from natural and manmade geomaterials with macro pores surrounding micro pores. From Coppola (2000) and Jongmans et al. (2003) view, double porositiness may arise due to root holes, worm holes and cracks in soils or the aggregated nature of the medium. Garga (1988) had reviewed that fissuring and cracking are the most common defects that could be observed in heavily overconsolidated and desiccated clay, whereas during soil compaction on dry side of the optimum moisture content, aggregation often occurs in agricultural soils and compacted soils as stated by Romero et al. (1999). In this research, NAPL will be used to study the migration of liquid between the two scales of porosity in aggregated soils by image analysis.

Contamination of the subsurface by hydrocarbons is one of the most challenging environmental problems because they contaminate the subsurface through accidental spillage or poorly designed disposal. Petroleum products such as benzene, toluene, ethylbenzene and xylene as well as chlorinated solvents are some of the most commonly encountered contaminants resulting from industrial activities as explained by Wang et al. (1996). These compounds usually exist in the subsurface in the form of NAPL because of their low aqueous solubility due to their non-polar molecular structure as stated by Pankow and Cherry (1996). Because of their low solubility in water, residual NAPLs constitute a long-term source of groundwater contamination. NAPLs are able to migrate to the water table and eventually become trapped in the water-saturated zone as residual ganglia occupying one or few pores and held in place by capillary forces.

1.2 Problem Statement

Water contamination by NAPL during agricultural activities as well as oil and gas activities is a concern in this era. A lot of research had been carried out to study the migration of NAPL in soil. So far, not many researches were done using image analysis to study the migration of NAPL in double porosity aggregated soil. In this research, image analysis is used to reproduce a dynamic NAPL saturation profile during experiments and to analyze the result of the NAPL migration in the aggregated kaolin of double porosity through lab experiments. Besides that, very little research had been done so far to study effect of different moisture content on migration of NAPL in aggregated soil. Through this research, effect of different moisture content can be determined by comparing the results from image analysis.

1.3 Objectives of Study

In any research, there are some objectives to be achieved. In this research, the objectives are:

i. To create the aggregated kaolin samples with different moisture contents in the laboratory.
ii. To analyze the migration of toluene in the aggregated kaolin samples by using image analysis.
iii. To study the effect of different moisture content on toluene migration in the aggregated kaolin samples.

1.4 Scope of Study

In this research, samples of kaolin aggregates will be prepared with different moisture contents of 28%, 30% and 32% respectively. The experiments will be conducted at least once for each moisture content to achieve consistency of NAPL migration. Then, a physical acrylic model with size of 10 cm x 5 cm x 30 cm will be prepared in the laboratory to accommodate a kaolin aggregates samples with size of 10 cm x 5 cm x 10 cm. Toluene will be poured into the kaolin aggregate samples while pictures will be taken using a camera and time will be taken until the toluene settles down. Next, image analysis will be conducted by using Image Pro-Premier 9.1. Lastly, the migration of toluene in aggregated kaolin samples will be studied and analyzed through images captured from DSLR camera.

1.5 Research Significance

The research provides a clearer study and analysis of migration of NAPL in the aggregated kaolin samples with different moisture contents by using image analysis. Image analysis will reproduce dynamic NAPL saturation profile during the whole process of experiment until the NAPL settles down. The result is beneficial to agriculture as well as oil and gas sectors in order to overcome oil spills problem that might happen during agriculture activities and oil and gas activities in the sea. Besides that, image analysis is a safe, low risk and cost effective method to do analysis on this research as it is non destructive and non intrusive to the whole process of experiments as well as to the environment. Hence, it is a reliable method chosen by many researchers to conduct their experiments without harming the environment.

CHAPTER 2

LITERATURE REVIEW

2.1 Non Aqueous Phase Liquids (NAPLs)

NAPLs are a type of chlorinated compounds or the products of petroleum hydrocarbon/products. NAPLs are often found or encountered at sites that are contaminated, especially at chemical production and industrial manufacturing facilities as stated by Kaluarachchi (2001).

NAPLs are divided into two types; LNAPL and DNAPL. LNAPL are those liquids that are less dense than water, mainly petroleum products such as gasoline, toluene, benzene, xylene and ethylbenzene. Petroleum products are usually low molecular weight hydrocarbons of which the water solubility is almost similar to chlorinated hydrocarbons. Chlorinated hydrocarbons are compounds with low molecular weight and almost immiscible in water. They have volatile properties and also classified as DNAPL. DNAPL are those liquids that are denser than water. Some other examples of DNAPL are coal tar waste, creosote-based wood-treating oils, chlorinated solvents and polychlorinated biphenyl compounds (PCBs).

2.1.1 Characteristics and Behavior of NAPLs

The migration of NAPLs in a medium is divided into two types of conditions; through unsaturated zone and through saturated zone as stated by Kehew (2006).

In an unsaturated porous medium, migration of NAPLs behaves in a way similar to that of flow of water. A capillary suction is applied on the NAPLs when the fluid is below the level of saturation of pores. This condition is similar to that applied on water but water is a more adhesive medium compared to non-polar organics when in contact with soil sub-surfaces. NAPLs in two or three phase unsaturated system is also known as the non-wetting fluid. This is because water, also known as wetting fluid, normally fills up the whole surface of solids in the medium. The movement of NAPLs also varies through wet porous medium and through dry porous medium. Hence, different moisture contents in porous medium will also affect the migration of NAPLs.

Initially, a NAPL is released into an unsaturated zone and it will move downwards by gravitational forces. The fluid will then be resisted by capillary forces during the stage of residual saturation development. To pass through the medium, the NAPL is to remove the existing pore fluids where it is easy in the pendular zone due to the par of filled pores. Rate of movement of fluid is highly caused by the viscosity of fluid, which is the internal friction within the fluid that causes movement resistance, and also the size of grain of soil. Coarse-grained soils tend to have a lower residual saturation of water and hence it is easier to migrate a NAPL through them. When the NAPL reaches the funicular zone, the rate of movement becomes slower due to pressure build up against the resistance of the higher saturation percentage of water. The condition of pendular saturation, funicular saturation and residual air is shown in the Figure 2.1. Migration of DNAPLs and LNAPLs in the unsaturated zone is similar. In a condition where the residual saturation is achieved and exceeded, the fluid moves downward to the water table. At that point, DNAPLs will behave differently from LNAPLs. A layer of DNAPL might form a top layer at the saturated zone but the fluid will permeate through the water table under sufficient pressure due to its high density to the first layer of material with low permeability.

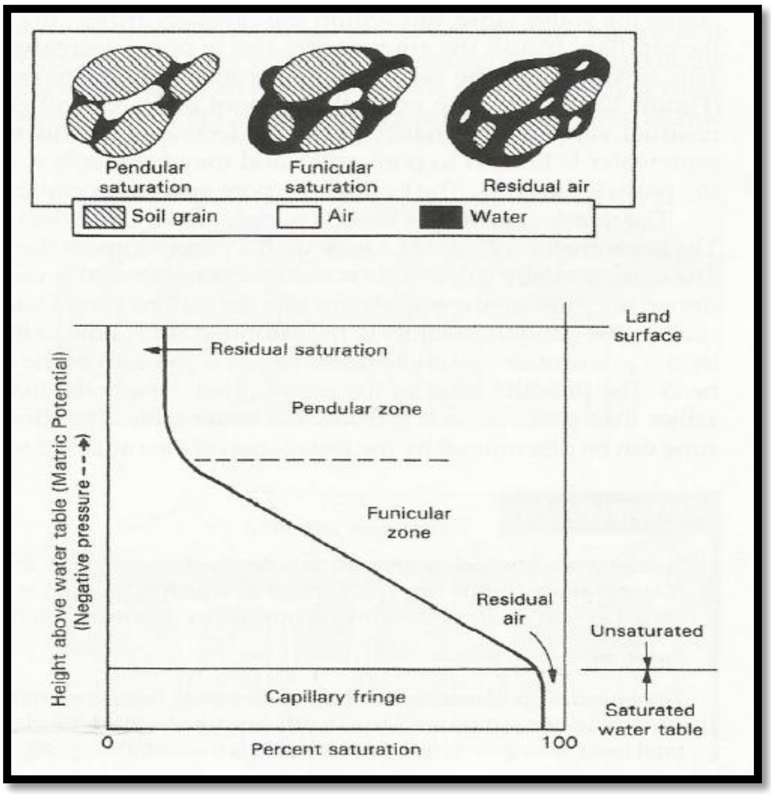


Figure 2.1: Soil water retention curve and classification of soil moisture zones

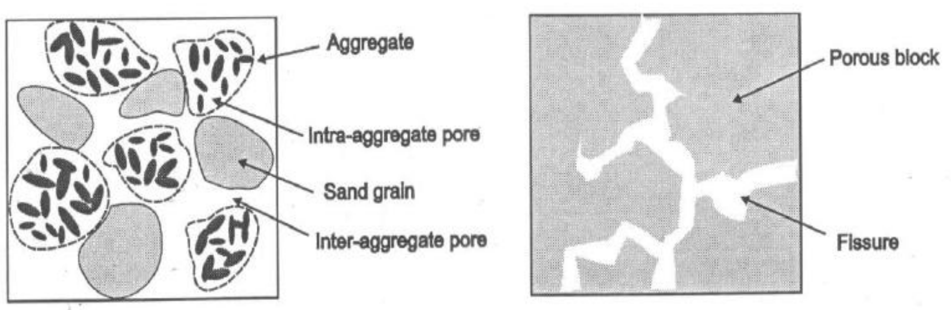
Source: Kehew (2006)

2.1.2 Toluene

Toluene ($C_6H_5CH_3$) is harmful to human skin, mucous membrane and nervous system as it is one of the most dangerous indoor pollutants among volatile organic compounds (VOC) as stated by Chen, X.M. (1984). It is a kind of aromatic hydrocarbon which possesses low olfactory threshold concentration, and the threshold limit value of toluene vapor indoor concentration is 0.05 ppm according to the indoor air quality standard as said by Huang et al. (2012). Toluene usage is wide and closely related to our daily life. It is used widely in adhesive & ink manufacturing and thinner formulations, dilutants for varnishes, lacquers and enamels. Besides, it is also used as solvent, industrial feedstock, and as an additive to gasoline to boost octane ratings. Toluene is a colourless liquid that is not soluble in water and it is a non-mutagenic and carcinogenic compound. In addition, toluene is also a volatile liquid and hence it would have a propensity to migrate to the atmosphere following an environmental release but does not pose a hazard to the food.

2.2 Double Porosity

Double porosity refers to two scales of porosity in a mixture. In soils, double porosity refers to the micro pores (intra-aggregate pores) and macro pores (inter-aggregate pores) and it is closely linked to low permeability and high permeability respectively. Double porosity theory in natural geomaterials is initially discovered by Barenblatt et al. (1960). This concept is about a fractured rock formation that consists of two media, which are the fractures (inter-aggregate pores) and the matrix blocks (intra-aggregate pores). Both have their own characteristic properties and behaviour. The primary porosity or the matrix blocks is in between the inter-aggregate pores with low permeability meanwhile in the secondary or fracture porosity, those are with low storage capacity with high permeability such as fractures. The concept of double porosity is presented as in Figure 2.2 below.



(a) Aggregated soil (b) Fissured porous medium

Figure 2.2: Concept of double porosity

Source: Koliji (2008)

Natural and manmade geomaterials usually exhibit the two scales of porosity. Various researches had been done and they stated that fluids especially NAPL prefers to flow through the secondary porosity which includes fractures, fissures, cracks or inter-aggregate pores. Secondary porosity represents the predominant pathways for fluid movement as the voids in between them are larger and highly permeable as mentioned by Sara (2003).

2.2.1 Double Porosity in Natural Media

Double porositiness in natural geomaterials might be caused by root holes, worm holes and cracks as stated by Jongmans (2003) or by the aggregated characteristic of the soil medium as said by Coppola (2000). Beven and Germann (1982) also proposed that double porosity in soil might be due to soil fauna, natural soil pipes, and fissures. Fissures and cracks are the most common observation that can be found in heavily consolidated clay as mentioned by Garga (1988) while aggregation often occurs in agricultural soil and compacted soil as stated by Romero et al. (1999). Double porosity will occur in agricultural soil during the activity of preparing land for growing crops where the soil aggregates will be separated by inter-aggregate pores as stated by Ghezzehei and Or (2003). This will cause the soil's fabric to have two pores system which are the intra-aggregate pores and the inter-aggregate pores as stated by Bagherieh et al. (2009) where they are associated with low permeability and high permeability respectively.

2.2.2 Double Porosity in Artificial Media

Double porosity characteristic in soil can also be created in the laboratory and it had been done by a numbers of researchers in the world for experimental studies. In a research, Coppola (2000) conducted an experiment to predict water retention curves by using aggregated clay to obtain water retention data. The aggregated clay was initially saturated before subjected hydraulic conductivity test and falling head test as well as crust method for unsaturated hydraulic conductivity. Aggregated samples were placed on a medium-textured sand column and the suction head was observed using tensiometers. A layer of high hydraulic resistance mixture was applied on the surface of the samples and water supply at the inlet was regulated using a Mariotte feeding column. In this research, Coppola (2000) revealed that the soils contained two pore systems which were having two modes of approach that allowed for separation of the porous medium into inter-aggregate pores and intra-aggregate pores where double porosity existence was found. Lewandowska et al. (2005) then conducted an experiment to show that double porosity can be created in laboratory by mixing clayey sintered spheres materials which have minute pore size with larger pore size of uniformly distributed sand to produce two distinct pore sizes where double porosity can be traced. Another research was carried out by Li and Zhang (2009) to study the formation of double porosity in compacted and decomposed granitic soil as well as the progression of microporosity structure in the samples throughout the wetting-drying process. The formation of inter-aggregate pores and intra-aggregate pores were seen during compaction and the inter-aggregate pores were very compressible when stress was applied.

2.3 Image Analysis

Image analysis is a type of computer analysis that is used to extract meaningful information from images which includes identifying shapes, counting objects, determining colors and also measuring object properties. Edge detection, shape detectors, color-based segmentation, and image thresholding are common image analysis algorithms. A detailed statistics can be obtained from images to provide human analysts with additional quantitative and qualitative data through the combinations of these common image processing techniques with region analysis functions.

2.3.1 Image Pro-Premier 9.1

Image Pro-Premier 9.1 is a useful tool to ease the process of capturing, processing, measuring, analyzing and sharing images as well as valuable data. Image Pro-Premier 9.1 provides features which include capturing images and videos, process and enhancement, measurement and quantification as well as counting and classifying objects.

2.3.1.1 Capture Images and Videos

Image Pro-Premier 9.1 ensures a superior capture experience as it instantly captures an image while live preview is running without loss of data. Besides that, it records quick experiments that last for longer periods of time which is suitable to be used in this research.

2.3.1.2 Process and Enhance

Image Pro-Premier 9.1 is equipped with auto alignment tools that enable the alignment of individual images or images in a sequence for translation, rotation or scaling inaccuracies. This software has HDR processing which allows a HDR image to be created out of a sequence of images where different exposures of the same scene will be presented using the widest possible range of dark to light pixels. Overlaying and comparing images can be done with both live images and previously captured images. Image compare workspace allows the placement of semi-transparent version of images on top of each other so that we can clearly distinguish the differences and similarities between images. It can be readily observed and saved as new images for report purposes or for more analysis. On the other hand, extracting and merging colour channels are possible using this software. It easily combines and separate images into RGB, HSL or HSI colour channels. Moreover, it can reduce noise and enhance details with filters by removing background noise and reveal hidden details with image processing filters and previewing filters on an active image for instant result before applying filters.

2.3.1.3 Measure and Quantify

Calibration of images for analysis can be easily done using spatial and intensity calibration tools. It comes with auto calibration feature which uses a stage micrometer to automatically calibrate an image. Besides that, we can also detect and measure the distance between edges along a defined line or changing intensity levels automatically. Movement of object can also be tracked manually or automatically by following cells, particles or other objects as they move through time and space. Objects that have faded out of view or moved out of working space can also be tracked using Image Pro-